
An In-depth Investigation of Technology Management Process in the Metal Processing Industry

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Abstract:

Purpose: This study investigates the technology management sphere within an organization from a process approach perspective and explains the technology management process (TMP) and its course and dynamics, along with circumstances influencing it, to a large extent.

Design/Methodology/Approach: The study employs the multiple-case-study methodology to investigate the process approach to Technology Management (TM) in manufacturing companies. The investigation is carried out in several metal processing companies. In-depth observations are collected, and visualization techniques on flowcharts are employed for modeling and presenting the generalizations.

Findings: From the study, a general TMP is elaborated, consisting of a sequence of four major steps interspersed with economic evaluation. The process is characterized by modularity, and it is abundant with many feedback loops and repeated assessments, which support architectural knowledge creation. The study implies that learning sources and means are the crucial factors influencing studied TMP.

Practical Implications: The study provides practical knowledge of TM, which will help accelerate activities related to developing and implementing new technologies in manufacturing companies that use similar technology components. Identifying the main circumstances of TMP make it easier to achieve higher productivity.

Originality/Value: The Business Process Management approach to TM's investigation in companies provides a refreshing view on how they deal with technologies. The study shows that the real TM is more complex than it might have seemed from widely discussed literature models. An important observation is the by-the-way learning phenomenon. This learning is spread over time and takes advantage of emerging opportunities from diverse sources.

Keywords: Technology management, technology and innovation studies, in-depth study, technological knowledge, and learning.

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1. Introduction

Technology and technology management (TM) plays a crucial role in almost every type of enterprise, and the world is becoming ever-more saturated with technologies. The technology issue is particularly important in manufacturing industries, as research indicates that companies with higher TM capability levels can achieve better business performance (Wu *et al.*, 2010). It is no wonder that research on technology adoption is still among the hot topics in technology studies (Lee and Kang, 2018).

The literature on TM provides conceptual models, most of which consider the management of technology using a multilevel approach (Phaal *et al.*, 2001). These models provide insights into companies' fundamental steps from a technology's introduction to its elimination. Even though literature models often refer to processes, a strict exploration of organizational processes occurs on a limited scale. Also, empirical studies on TM, as with the technology management process (TMP), are infrequent. On the other hand, the Business Process Management (BPM) approach offers a well-established and repeatedly proven methodology for investigating organizational processes.

This study aims at identifying a real flow of TM, seen as the organizational process in selected metal processing companies. It also aims to deepen the exploration and understanding of the streams of process activities and the discovery of interrelations among them and the main factors influencing TMP course and dynamics. An identified TM state will be confronted with the TM concepts presented in the literature. A qualitative research strategy is employed for this study, and a multi-case study is performed, within which TMPs are identified in companies by following cases of specific technologies. The TMPs are visualized using a flowchart technique.

2. Literature Review

2.1 BPM Approach

BPM is a popular management approach exploited by all kinds of organizations around the world. In the opposition of organizational functions in BPM, the primary role plays a process. Regarding process management, the literature mentions 'process simplification', 'process improvement', 'process redesign' (Lee and Dale, 1998), 'workflow management' and 'business process reengineering' (Ko *et al.*, 2009). The latter term is particularly important for this approach because of the fundamental work by Hammer and Champy (1993), which is considered the beginning of BPM.

BPM is a wide, process-oriented management discipline enclosing workflow as its fundamental component (Hill *et al.*, 2008). The BPM concept takes much from Total Quality Management (Niehaves and Plattfaut, 2011). As Ko *et al.* (2009) state, BPM includes various paradigms and methodologies from organization management theory, computer science, mathematics, linguistics, semiotics, and philosophy; thanks

to these, BPM is a cross-disciplinary 'theory in practice' subject. The literature emphasizes that what is known as 'process orientation' is also embodied in two popular models of excellence: the European Foundation for Quality Management and the Malcolm Baldrige National Quality Award (Lee and Dale, 1998). Now, BPM is, in many ways, supported by information systems that interpret business processes and support and monitor their execution (Pourmirza *et al.*, 2017).

The concept of the organizational/business process, which is crucial for this study, is at BPM's heart. Perhaps the best definition of a business process is a step-by-step approach to a specific business problem (Havey, 2005). This brief definition highlights what is most important in a business process: an inherent occurrence of a sequence of actions in a process and the irrevocable need for a business goal. In the popular quality management standard, ISO 9000, a process is defined as a set of interrelated actions that transform inputs into outputs (EN ISO 9000, 2015). The Workflow Management Coalition provides another quite formalized definition, an organization supporting BPM, which defines a business process as a set of one or more linked procedures or activities that collectively realize a business objective or policy goal, normally within the context of an organizational structure defining functional roles and relationships (Hollingsworth, 1999).

Hammer and Champy (1993) perceive a business process as a collection of activities that consume one or more inputs and create output as value for customers. Palmberg (2009) understands a business process as a horizontal sequence of activities that transforms an input (need) into an output (result) to meet the needs of customers or stakeholders. These two interpretations emphasize process inputs and outputs and process aims, which form the basis for understanding a business process. However, they do not exhaust all the important elements of a process. Others also mention trigger (or event), activity, organizational unit (or persons), input, output, control flow, information flow, organizational flow and material flow (Zellner, 2013; Forrest, 1991). These can be identified regarding a business process and used in an exhaustive process of identification and description.

The business process approach presents a comprehensive array of improvement options (DeToro and McCabe, 1997). The literature mentions four phases of the BPM: process design, system configuration, process enactment, and diagnosis (Ko *et al.*, 2009). The business process modelling is addressed to process the design phase and enables a common understanding and analysis of a business process (Aguilar-Saven, 2004). When preparing a process model, a comprehensive understanding of the process is necessary. Various methodologies support business process modeling. Activities occurring within a process are often at the core, but roles, actors, information flow, resources, and other factors can be tracking objects (Lin *et al.*, 2002). A process map or flowchart, as a kind of modelling methodology, is primarily focused on capturing activity sequences (Lee and Chuah, 2001).

2.2 Views on TM

New, disruptive technologies are undoubtedly a key factor in economic development and competitiveness. Various authors argue that a high economic growth rate, without high investment in technologies, is possible only in the short term (Pretorius and de Wet, 2000). An unfavourable scenario occurs when high investment in technologies does not lead to economic growth. This typically means there is trouble in strategic technology management (Pretorius and de Wet, 2000). One of the popular study streams in TM literature is a strategic view on TM; technology utilization, technology changes, and plans in this field is linked to a company's competitiveness (Ahmad and Schroeder, 2011; Liu and Barrar, 2009; Rothaermel and Alexandre, 2009; Wu *et al.*, 2010).

The strategic view on TM is by no means unified, and authors present slightly different concepts. Some study the relationships between strategy and technologies; some see TM as a strategy component, and others acknowledge a separate technology strategy. According to Ahmad and Schroeder (2011), a technology strategy (learning-based approach) is a long-term vision for managing technology that sets a consistent decision-making pattern to foster the creation and exploitation of knowledge to attain superior competitiveness. Others see TM as closely tied to innovation management and knowledge management (Cetindamar *et al.*, 2009). TM's strategic position is emphasized by the fact that it is under the influence of two factors – the commercial pull of a new product and the push of technological possibilities (Bernstein and Singh, 2006; Phaal *et al.*, 2004). Edler *et al.* (2002) argue that research and development (R&D) management is becoming a more important strategic instrument for long-term competitiveness. A corporate technology strategy is highly integrated into a corporate and business unit strategy.

Although technology's strategic value is unquestionable, its impact on companies' competitiveness and business performance are not fully clear. Some authors reveal that technology decisions linked to a company's competitive strategy positively influence business performance (Liu and Barrar, 2009). Others do not demonstrate a direct effect of components of a learning-based technology strategy on a plant's competitiveness, although the co-alignment of strategy components has a strong impact on competitiveness (Ahmad and Schroeder, 2011). Authors advocate that balancing internal and external technology sourcing can have positive implications for a company's performance, and a company can leverage its competitiveness and competency by incorporating technology from outside (Rothaermel and Alexandre, 2009). However, according to the study by Ortega *et al.* (2012), managerial practices from manufacturing strategy and technology management have no significant link to companies' operational performance.

Knowledge is an issue that heavily affects TM in industrial companies (Wu *et al.*, 2016; Kropsu-Vehkapera *et al.*, 2009). Knowledge management is critical in many TM fields, namely in technology forecasts and technology strategy and technology

acquisition or development (Kropsu-Vehkaperä *et al.*, 2009). Scholars emphasize that the knowledge structure in an organization is closely related to a company's innovation performance (Zhou *et al.*, 2018; Yayavaram *et al.*, 2018). Two components of technological knowledge are highlighted in the literature: technology domain knowledge and architectural knowledge (Henderson and Clark, 1990; Tushman and O'Reilly, 2002; Zhou *et al.*, 2018). Domain knowledge concerns a particular technology domain, including its technical, scientific, and application background.

Architectural knowledge is driven by architectural innovation, which relies upon the reconfiguration of product components; thus, it concerns how to reconnect/reconfigure product components/technologies (Henderson and Clark, 1990; Carnabuci and Operti, 2013; Yayavaram *et al.*, 2018). Research shows that, when innovations are impossible in the technology field or limited, companies eagerly turn to innovations based on architectural knowledge (Zhou *et al.*, 2018; Han, 2017), even in small outsourcing companies (Han, 2017). The knowledge structure is also a key issue when seeking alliance partners (Yayavaram *et al.*, 2018). Additionally, knowledge management, including knowledge learning, is a particularly important factor for building technological capacity (Wu *et al.*, 2016; Yu *et al.*, 2017).

Another issue attracting scholars' attention concerns the question of what TM consists of. The TM model by Gregory (1995) acts as a foreground viewpoint. Gregory (1995) identifies five processes forming the TM in a company: (1) identification of potential technologies, (2) selection, (3) acquisition, (4) exploitation, and (5) protection of technology-related knowledge. McCarthy (2003) identifies a 'strategy configuration chain' that is formed by four management tasks that refer to technology in a company: (1) technology classification, (2) technology selection, its (3) adoption, and (4) exploitation. These are consistent with those from Gregory (1995); the difference is that they are elements of a broader model, and the tasks wrap around and co-influence a company's technology strategy, resources, and value offered in the market. In these models, the concept of 'process' is intensively exploited but is perceived not as a rigorous business process as in a BPM approach but as a symbolic set of certain tasks/actions. They are derived from speculative deliberations, and some authors underline that listed processes/activities are not explicitly linked with each other (Cetindamar *et al.*, 2009).

Surveying the TM literature results in several doubts and questions. When it comes to new technologies that destroy entire industries, the influence on company competitiveness is obvious and unquestionable. The meaningful question is how companies take competitive advantage by introducing the technologies that are generally known. The literature proposes a series of activities concerning the TM; they look logically related and appear to follow one another. However, there are very few empirical confirmations for how companies undertake these activities and whether they equally apply to all activities mentioned by the literature. Finally, what kind of factors influence the TM dynamics in real companies? Additionally, the

knowledge factor lacks sufficient empirical study. An interesting question is how different kinds of knowledge (domain and architectural) are created or acquired.

2.3 TMP in Literature

Some authors long ago postulated to treat the TM in a company as a process/processes in conjunction with other organizational processes. The management of technology and the application of technological knowledge cannot be divorced from other parts of a business, such as business development, organization, and human resources (Maffin, 1998); Milewski *et al.* (2015) investigated as 'technological process innovation,' which is defined as a distinctive organizational phenomenon characterized by a firm-internal locus. It consists of components like the mutual adaptation of new technology and existing organization, technological change, organizational change, and systemic impact. This study considers the wide co-influence of technological changes, and a company's organizational system and investigation occurred in large companies, and the technological process innovation lifecycle considered four phases: ideation, adaptation, preparation, and installation (Milewski *et al.*, 2015).

Cetindamar *et al.* (2009) tracked the TM within the pharmaceutical company Glaxo. Authors identified the TM system and a sequence of activities that can be perceived as a meta TMP, starting from a business strategy and leading to benefits demonstration. The Developed TM model is conceived as the development and exploitation of technological capabilities constantly. It embraces crucial TM characteristics within a large bureaucratic corporation operating on advanced and unique technologies. Levin and Barnard (2008) identified 27 TM routines in large corporations, typical for disruptive technologies, and the authors admit that these routines are processes. The routines/TMPs elaborated by these authors are organized into four categories: producing scientific and technological knowledge, transforming knowledge into working artifacts, linking artifacts with user requirements, and providing organizational support.

Phaal *et al.* (2001), based on the five-process model (Gregory, 1995), proposed a TM assessment model that implies drilling into companies' activities. They presented a series of TM process-visualizations for dry-powder and wet-paint technologies. This TM assessment discovered a gap between the existing business processes and the five-process model's conceptual framework (Phaal *et al.*, 2001).

TM thrives on capabilities to adopt new technologies. It is perceived as a collection of routines/activities for executing and coordinating the various tasks required to manage technology (Cetindamar *et al.*, 2009), and the process approach allows companies to manage technological capabilities better. The literature indicates more advantages of the process view on TM. For example, the process approach is a remedy for the ineffectiveness of a piecemeal approach to technology management (Ahmad and Schroeder, 2011) and allows us to better understand the immanent dynamism

accompanying TM (Cetindamar *et al.*, 2009; Ahmad and Schroeder, 2011). At the same time, authors underline that the existing literature concepts for TM do not reflect sufficiently the day-to-day operations of enterprises (Sahlman and Haapasalo, 2012), primarily because of this field's complexity. Therefore, this study examines TM as an organizational process – a continuous sequence, from the first triggering activity to the last. This idea will be deployed in business entities dealing with 'usual,' not disruptive, technologies.

3. Research Methodology

This study employs a multiple-case-study methodology. Case study research is a qualitative approach in which the investigator explores a bounded system (a case) or multiple bounded systems (cases) over time, through detailed, in-depth data collection from multiple sources (Creswell, 2007). Investigating research objects relied on a script that considered theoretical knowledge demanding empirical verification and research gaps identified in the literature (Yin, 2014). Using this approach, an issue is examined through various lenses so that multiple facets of a phenomenon can be revealed and understood (Baxter and Jack, 2008). This methodology was applied to investigate the process approach to TM in metal processing companies. The investigation scenario (research script) included three main stages: (1) direct interviews with managers, (2) company documentation studies, (3) observations of facilities, and organizational routines in chosen departments of the investigated subjects. During company visits, the researcher's entire attention was devoted to comprehensively understanding the respective company's TM organizational process.

Company investigations lacked any initial assumptions, meaning that it was not a point to find in companies any literature components, like the five-process theory of TM by Gregory (1995) or others. The point was to recognize in each company the first activity in the sequence of TM according to managers and to follow that sequence until arriving at the last one, as reported by managers and supported by evidence. A flowchart technique is employed for process visualization – a graphic representation of a logical sequence, work or manufacturing process, organization chart, or similar routinized structure (Aguilar-Saven, 2004). It allows for expressing the information flow, decision points, and business processes' roles in a diagrammatic way (Ko *et al.*, 2009). For each studied case, a flowchart of a chosen TMP was developed.

Four cases from the metal processing industry were studied. Company A has 400 employees and manufactures advanced human body implants and medical tools used by orthopaedics and traumatology. Company B specializes in a wide range of farm machinery like mowers, rakes, wire-trap tools, tedders, and snowploughs and employs 600 people. Company C is a technology maker that produces individually tailored machines and technical devices for food processing companies. It also provides machining services, tooling services, and automation for the client's production processes. It employs 67 people. Company D has 60 employees and produces decorative metal designs for home, garden, and public spaces. Each of the studied

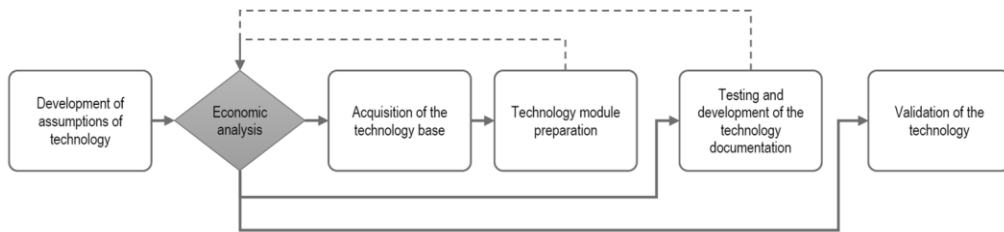
companies has a different specialization, their respective bundles of technology differ significantly, and the companies are different sizes in terms of turnover and employment. None of them deal with disruptive technology, which is typical in this industry. These boundary conditions allow for a wide and comprehensive look at TMP.

4. In-depth Studies in Companies

4.1 Company A

Company A produces a small series and single-unit products. It operates using various technologies, mainly involving machine metal processing, 3D printing, cleanroom processing, and gas sterilization. The technology of compression moulding in the cleanroom has been chosen for TMP investigation. It is employed for manufacturing surgical devices for implantation treatment. The flowchart of TMP referring to this technology is presented in Figure 1 below.

Figure 1. *Flowchart of TMP of compression moulding in the cleanroom*



Source: *Own study.*

The TMP process began with the CEO's decision to start working on this technology. The first step of TMP is the development of technology assumptions. At this stage, the framework parameters of the products delivered by this technology are determined, namely x-ray transparency, appropriate rigidity, dimensional stability, no deformability features, and biocompatibility with human tissues. The first step of TMP initially tries to answer exactly what technology is needed for the company.

When technology assumptions were ready, the company carried out economic analysis based on evidence; a trial batch was made experimentally and comprehensively assessed. A sample was tested, and its characteristics were compared to the best competitive ones. The company's sample was better than those produced by competitors and less expensive. The performed tests and economic analysis provided justifications for further work on this technology. The next step was acquiring the technology base, which required purchasing an appropriate device (the press) and its adaptation to the assumed technology's specific needs.

The next step of TMP was building the individually tailored module of the technology. Particularly, the company had been preparing a technology control layout, which

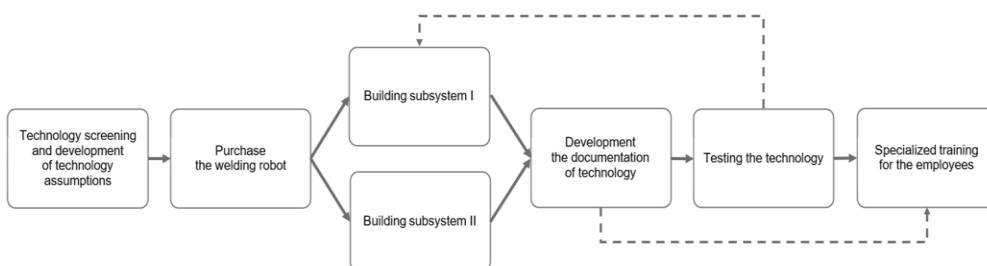
allows for smooth regulation of a key control production process parameter – pumping temperature. This step also included experiments aimed at the determination of an appropriate set of parameters. When this step was finalized, the economic analysis was performed once again (see return loops on the flowchart in Figure 1).

The economic analysis allowed the movement to another TMP step: testing and technology documentation development. The company's appropriate department carried out a series of tests referring to material, resistance, cytotoxicity, resistance to sterilization, material rigidity, dimensional stability, and output parameters. The specifications and functional documents necessary for using the technology in the production process were developed based on test outputs. The process from the decision to start working on the technology to the beginning of routine production took two years. Consultation with medical experts regarding the technology occurred several times. The company's effects are perceived as positive, and cost reduction and improvement of technical product parameters occurred.

4.2 Company B

Company B produces a small range of farm machines, and production is highly dependent on the seasons. The company operates in several technology groups: machine processing, milling and rolling, surface processing, sanding and painting, and metal plastic processing/cutting and materials joining. The TMP of welding robots was tracked, and the flowchart model is presented in Figure 2. First, clearly separated actions bundled in the process were devoted to market analysis. This focused on technological possibilities in metal welding and, widely, on prevailing trends in metal processing. The technology screening step also involved a patent database search and examining technological solutions existing in the market. Along with technology screening, concrete requirements regarding welding robots in the company were developed.

Figure 2. The TMP of welding robots in company B.



Source: Own study.

Having clear assumptions of what is expected from welding robot technology in the company, an appropriate solution was found in the market, and the purchase proceeded. Two parallel activities occurred afterward: (1) outfitting the station with

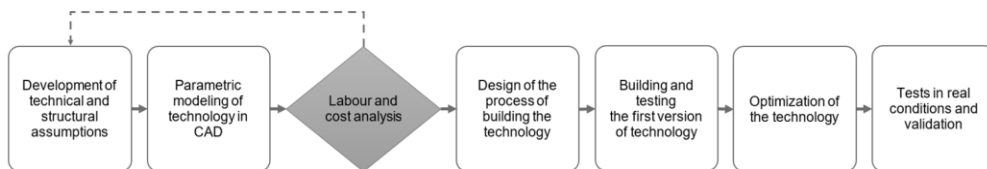
additional equipment to provide proper mounting and working conditions, and (2) creating the control system. These two were the technology subsystems that were attached to the purchased robot. Testing the technology and documentation preparation formed a repeating loop a few times. Testing occurred under real working conditions so that various kinds of test series were manufactured. By exploiting the robot's abilities, it gradually became apparent that it needed to be equipped with additional components (subsystem I, Figure 2).

Developments and updates to the technical documentation accompanied the development and production of additional equipment. When separate parts of the technical documentation were ready, the training of personnel as to possible. The final stage of technology implementation and TMP was specialized training for the employees who were to become the robotic station operators. It lasted approximately 26 months and was perceived as successful by Company B. A nearly 60% reduction in welding time was reported, and a significant increase in the productivity of the manufacturing department, along with quality improvement, were recorded.

4.3 Company C

Company C specializes in delivering individually tailored technologies for food manufacturers. It uses several technologies for metal processing like machining, plastic working, and electro-erosive machining. The in-depth study was carried out on the technology of a pet food packing line that the company created for installation in a client's facility and, after some modifications, to sell it to other food processing companies. The flowchart model of the TMP of the automatic packing line built by Company C is shown in Figure 3. The first step consisted of developing guidelines, along with technical and structural assumptions. During this stage, specific tasks and functions that the device had to perform were designated, the structure was defined, and the initial selection of materials and components was performed.

Figure 3. *TMP of automated lines for pet food packing*



Source: *Own study.*

Using specifications, developers created in the CAD environment a parametric model of the designed device. The next step was an analysis of the labour and cost intensity for the technology in design. Afterward, it was necessary to decide to proceed with the design's implementation or go back to the assumptions stage (see the back loop in the flowchart, Figure 3). Based on the modelling work results, the company started

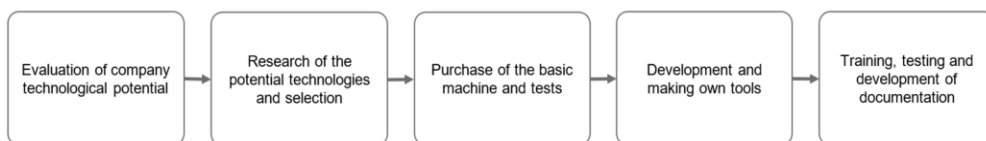
designing the process for building new technology. Previously designed models contained only frameworks and specified nodal points of the technology so that the design for the execution of the technology demanded a huge amount of creative work. Many sources (patent records, industry fairs, internet services) were exploited to identify and check many detailed technical issues, including execution methods. Technical specifications for the emerging technology were developed, and materials and necessary components were gathered as necessary for the next stage.

Building and testing the first version of the production line for pet food packing was the next TMP step, lasting 12 months. This allowed for the discovery of previously undetected structural errors, and necessary corrections were implemented. The testing occurred within simulated operating conditions. The next step was to optimize the developed technology; several changes, adjustments, and regulations were implemented at this stage. Finally, the closing version of the technology emerged and was installed in the client's company facility and tested under real conditions. The technology was validated under initially established assumptions, and the whole TMP lasted 36 months.

4.4 Company D

Company D produces a small range of decorative metal items and operates on conventional metal processing machines. Its technologies are widely available and are related mainly to the plastic processing of structural steels. The technology of metal sheet formation by grooving was the focus of the TMP investigation. This company began working on this technology under the direct influence of a customer's requiring it for a product. The flowchart of the process is presented in Figure 4.

Figure 4. TMP of metal sheet formation by grooving technology in Company D.



Source: Own study.

The first step involved a careful evaluation of the company's technological potential, both in terms of available machinery and staff competencies. The company tried to produce a client order based on available technologies, but it seemed impossible. Thus, the next step was identifying potential, available technologies that could be applied for processing the product demanded by the customer. The market analysis involved numerous talks with technologists from other companies in the sector, studies of dozens of online sources, and technology producers' releases demonstrating technology potentials. This research allowed them to choose the appropriate technology.

Following this decision, the company purchased a metal sheet grooving machine and installed it in its facility, where a trial batch of products was manufactured. After technology tests, the company began preparing a set of tools necessary for executing new customer orders. The company's own tools were designed and executed within its own facility. The last stage of the TMP included carrying out training staff on the technology's operation; this was combined with testing the technology's capacity. The TMP was declared finished with technical documentation preparation, and the total process lasted 18 months. It is very peculiar that Company D does not use any procedures to guide the TMP in any of its steps. The entire process was spontaneous and involved many errors.

5. Discussion

The process view on TM provides a refreshing insight into how companies deal with technologies. Further lessons can be learned from comparing the investigated TMPs with literature TM models. Table 1 presents the occurrence of the five TM processes by Gregory (1995) in TMPs identified in case studies. The first one from the five processes – identifying potential technologies – appeared in only two of the four TMP sequences (Company B and Company D). Moreover, in Company C, identifying potential technologies appeared only residually to identify fragmented solutions that may be useful in tracked technology development.

Table 1. *Investigated TMPs with reference to Gregory's model.*

TM model by Gregory (1995)	Company A	Company B	Company C	Company D
Identification of potential technologies	Not present as a process step/activity	A recognisable part of the process sequence	Occurred when building the technology, referred to components	Occurred in the process
Selection	Not mentioned as a noticeable TMP activity	Indiscernible, integrated with other activities	Referred only to some technology components	Occurred in the process
Acquisition	Appeared as a separate process step	A process step	Did not occur	Occurred in the process
Exploitation	Only for testing purposes	Occurred only to perform tests	For tests in the other party's facility	Only for testing purposes
Knowledge protection	Not identified in the process	Not identified in the process	Not identified in the process	Not identified in the process

Source: Own study.

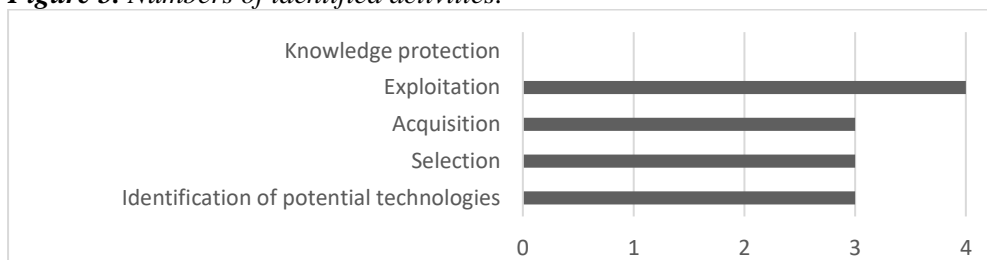
Technology selection appeared as a clearly indicated set of process activities only in one case (Company D). It is noticed in two more cases but does not account for a significant portion of process activities. Acquisition of technology is mentioned in three cases – Company A, Company B, and Company D – and is a distinct part of the

TMP sequence for all three. TMP investigated in Company C does not contain technology acquisition, but the technology is built by the company to justify not performing activities referring to acquisition. Technology exploitation is perceived by the researched companies as an integrated part of TMP as far as it is devoted to conducting tests on technology. During the investigations, it is suggested that technology exploitation is another organizational process – technology maintenance. As mentioned by Gregory (1995), knowledge protection has no direct reflections in any of the investigated TMPs.

However, it is observed that practical ‘protection’ behaviors are inbuilt in personnel working routines; they are reluctant to share detailed technical solutions. Most companies from the metal processing industry, including those researched, operate on a practical and tacit knowledge (Nonaka and Takeuchi, 1995; Anandarajan and Akhilesh, 2013), often emerging from widely known domain technology knowledge, which is difficult to protect by using formal instruments. The knowledge perspective will be considered below.

It is peculiar that the TMP investigated in Company D, which is characteristic of being the least advanced, looks to have best represented Gregory’s five processes, though not fully. This suggests that theoretical models can explain well only technologies created and acquired as a ‘packed box’ rather than being developed by the company. These observed TMPs indicate, as in other studies (Sahlman and Haapasalo, 2012; Phaal *et al.*, 2001), that the theoretical concepts do not adequately describe the reality of dealing with technologies. The number of standardized activities identified in the four investigated cases is presented in Figure 5 below.

Figure 5. Numbers of identified activities.



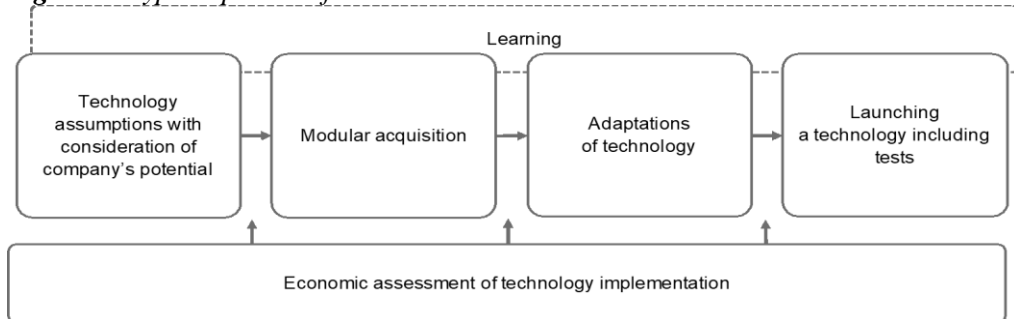
Source: Own study.

In-depth studies of TMPs, along with flowchart models, allow for the identification of typical activities occurring in a TMP. First, it is symptomatic that TMP is started by assessing a company regarding technology needs and development potentials. This is mostly expressed as a development of technology assumptions. In simple words, it consists of answering what is needed or possible, given a company's conditions, taking into consideration the company's strategic big picture. This TM stage is not explicitly mentioned by literature; however, according to this study, it covers an important set of activities, where many issues important for a company's growth are determined,

and important learning occurs. Another key step in the studied TMPs is technology acquisition, which is not simply purchasing a technology. In the studied cases, the modular approach is characteristic. Companies purchase technology, not as a black box; rather, they build it by adding modules. Consequently, along with the modular acquisition, another process phase is devoted to technology adaptation. Companies adjust technology ingredients, such as equipment, for specific expectations formulated beforehand as technology assumptions.

TMP's final steps always refer to carrying out several tests on the installed and modified technology, which accompanies the preparation of appropriate documentation and training for operators, if necessary. The end of TMP is perceived as having installed technology and introduced organizational routines for full-fledged technology exploitation. Further activities are not perceived by companies as a part of TMP but are included in technology maintenance. Studied TMPs also included activities that rely on performing an economic assessment of the employed technology, which can be done in several technology stages. If not explicitly disclosed, it exists as an incremental part of other process steps. The range of phases covered by the identified TMPs is like a range of activities, between 'ideation' and 'installation,' indicated in the technological process innovation (Milewski *et al.*, 2015; Hobday, 2005). The generalization of TMP carried out based on studied cases is presented in Figure 6 below.

Figure 6. Typical phases of the studied TMPs



Source: Own study.

The BPM perspective discovers different management borders for technologies within companies, compared to mainstream literature models. In all studied cases, the beginning of TMP is deeply rooted in new product development or possibly business strategy. Technology assumptions development (mentioned in companies A through C) is strictly tied to planned new product development or changes in existing ones. The decision to start working on new technology can be directly related to the response to clearly identified customer needs, as happened in Company C and Company D. The lessons learned from these cases indicate that TMP cannot be perceived as isolated because it is incrementally connected with the new product

development process. The processes of 'product development' and 'business strategy' serve as a trigger and substantial input for TMP.

Although not clearly indicated in the main theoretical models, empirical studies report similar embedding of the TMP. Karjust *et al.* (2010), who investigated a large composites manufacturer's technology route, demonstrate a close link between the TM and product family planning and product design. According to the study on TMP in the pharmaceutical company Glaxo Wellcome by Cetindamar *et al.* (2009), the process contains at its beginning a 'business strategy,' followed by a 'development and maintenance technology strategy.' Because Glaxo Wellcome is a multinational corporation dealing with disruptive technologies, the identified TMP differs in many ways but manifests many similarities to those identified in the four cases above. It also shows its end at the point when the technology is launched for stable production. The study even manifests an inherent necessity to consider pre-existing and subsequent processes when the TM is studied and analyzed in an organization.

Two kinds of technological knowledge, architectural and domain one (Henderson and Clark, 1990; Carnabuci and Operti, 2013; Yayavaram *et al.*, 2018), eventually appear in investigated TMPs. The knowledge factor plays a significant role and presumably can explain a dynamic of studied processes. The first process phase, mentioned in the scheme (Figure 6), is on producing and gathering outside a company the domain knowledge on the technologies that can be brought to a company. At the same time, the frame of architectural knowledge is predefined during this phase. Responsible people in companies try to foresee the most convenient combination of existing technical knowledge and new technical knowledge that is realistically obtainable. Simultaneously, technology assumption development is involved in determining architectural innovation, which is clearly seen in the cases of companies A through C, where the technology assumptions are strictly tied to planned new product development or changes in existing ones.

Modular technology acquisition, which appears in the second phase of generalized TMP in Figure 6, is especially relevant to the concept of architectural innovations (Henderson and Clark, 1990). The architectural innovations rely upon a new configuration of known technologies or product components. They are characteristic of subtle challenges that may have significant competitive implications (Henderson and Clark, 1990). At this stage, initial architectural knowledge leads to specific technology components; however, it still requires constant development and deepening. The issue, then, is how to configure a technology according to a company's individual concept and client needs, which occurs in subsequent TPM phases. Still, the domain technology knowledge is being developed, among others, through numerous tests, trials, and assessments. The literature mentions modular companies (Yayavaram *et al.*, 2018) that spread their knowledge base over many technology clusters.

However, in the studied cases, the modular acquisition of technology is due primarily to a lack of sufficient knowledge for how a technology will be precisely employed and configured and remaining flexible for the emergence of an optimal solution, which takes place primarily during the adaptations of technology phase (see Figure 6). The adaptations phase includes further knowledge creation, primarily from inner sources, by inner tests and tests with clients, experiments, individual experts hired temporarily, and economic assessments. The last phase is launching and final tests, which are very similar in terms of producing knowledge.

It is not easy to clearly separate the two kinds of knowledge present in studied cases. From an investigated object's perspective, both are equally important and obtained and produced during the TMP. However, domain knowledge looks mostly (but not exclusively) obtained from outside a company, while architectural knowledge is mostly (but not exclusively) produced within a company. Also, literature underlines that domain knowledge tends to be easily transferable (Henderson and Clark, 1990; Zhou *et al.*, 2018), while architectural innovations (knowledge) may have significant competitive implications (Henderson and Clark, 1990). The first TMP phase (the technology assumptions) appears important from an architectural knowledge viewpoint because it imposes a framework for upcoming architectural innovation.

In-depth studies of companies show that the issue is not the knowledge itself, but how to acquire appropriate knowledge efficiently and with little effort. Researched objects make serious efforts to consider various options and many learning sources to possess as easily as possible, potentially valuable, and useful technical knowledge. Architectural innovations rely upon a new configuration of known technologies or product components and give a company a competitive advantage (Henderson and Clark, 1990). Companies build knowledge for such an advantage during this long learning process, which is by-the-way learning. 'By-the-way' does not mean unimportant, but indicates how knowledge is obtained and gathered – incremental, long-time learning, taking advantage of occasions, expected and unexpected chances to possess some new insights, to understand better, to discover new relations between different technical variables and characteristics and to find new chances to reconfigure the technology ingredients. This is efficient knowledge, including prospects on how to outperform others who use these technology components.

Observations made in the studied companies indicate that learning, acquiring, and producing new knowledge is the main factor affecting the observed TMPs. The process lead time is between 18 and 36 months, while the 'hard' activities performed could be carried out in no more than a few months. Plenty of time is devoted to searching for new knowledge and learning opportunities. Many kinds of tests and analyses are focused on obtaining the new knowledge required in the processes; simultaneously, the lack of desired knowledge also lengthens process lead time by delaying and suspending decisions.

The authors mention the knowledge acquisition referred to in the TM (Cetindamar *et al.*, 2016; Levin and Barnard, 2008; Kfir, 2000), but not to the extent and level of importance observed in the studied TMPs. However, the literature on innovations and TM mentions knowledge creation as a spiral process that can trigger a new spiral of knowledge creation. These interactive spirals occur intra- and inter-organisationally (Anandarajan and Akhilesh, 2013; Nonaka and Konno, 1998). Learning observed in studied TMPs is largely similar to Liyanage and Poon (2003) underline, experience and learning practice lead to reflections and planning. Additionally, as also mentioned in literature sources, the experience of success and failure (Wu *et al.*, 2016) is an important learning component. Nonetheless, the literature fails to underline by-the-way learning consisting of lengthy acquisition and technological knowledge production, taking advantage of upcoming occasions and various learning sources.

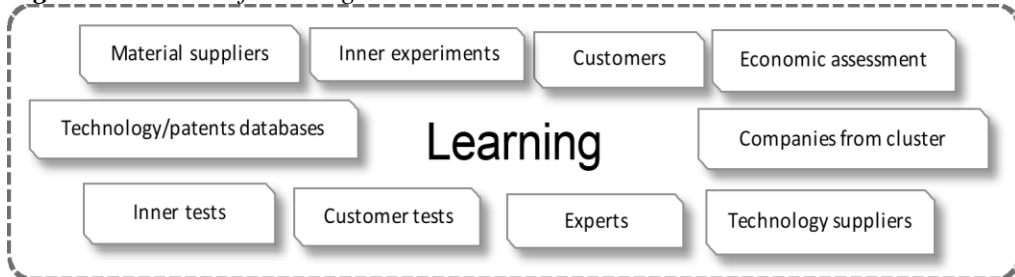
There are many ways (and sources) of learning that appear in studied TMPs. The process takes advantage of the knowledge provided by producers and suppliers of technologies or technology components, from many kinds of test technology models and their real modules and professional publications, including patent databases. Customers who give feedback and opinions on new products and their features are a precious knowledge source.

Companies also learn intensively from external experts. Company A provides an example of frequent learning from medical experts. Another source of learning is economic analyses, which frequently occur in TMPs; they are 'navigation points,' which input new knowledge and reduce the risk of choosing the wrong way in technology development. The sources of learning in the TMP is presented in Figure 7 below. A wide variety of knowledge sources are exploited through successive learning spirals (Nonaka and Konno, 1998), as mentioned above.

During this learning, intensive communication with a variety of a company's partners is essential, as is mentioned by Nair and Prakash (2009) (as specified in Figure 7). Observed learning contains exploitative and exploratory learning, as hypothesized by Yu *et al.* (2017). Authors underline internal and external learning (Maidique and Zirger, 2009); the former involves learning from experience, or 'learning by doing.' In studied cases, this mainly occurs when learning from inner tests, inner experiments, customer tests (performed by the company's personnel), and economic assessment conclusions.

The latter is mentioned as learning when users can use the product for extended periods (Maidique and Zirger, 2009), and it might be perceived differently, depending upon how learning occurs in studied cases. Learning from customers occurred in examined TPMs and learning from experts, suppliers, other companies within the business cluster, and databases.

Figure 7. Sources of learning observed in the studied TMPs.



Source: Own study.

According to Edler *et al.* (2002), ‘Fourth generation of R&D’ technology is a strategic instrument for long-term business competitiveness. This implies its close connection to strategy on the business unit level, which is noticed in the studied cases. The concept of ‘Fourth generation of R&D’ also presupposes technology development in place of needs and integration of various elements in the value chain (Edler *et al.*, 2002). This is consistent with the modularity and lengthened phase of technology adaptation observed in the studied TMPs. The identified TMPs are organized in such a way as to leave as much flexibility as possible by purchasing or building a technology module along with architectural knowledge. Modularity is noticeably supported by iterative economic evaluation, as is clearly demonstrated by TMPs in Company A and Company C. Flexibility, adaptability, and cost-effectiveness of technologies are key issues in McCarthy’s (2003) ‘strategy configuration chain,’ which is a model of TM.

6. Conclusions

By applying the BPM approach to investigating TM in companies, this study provides a refreshing view on how they implement technologies. The investigation focused on metal processing companies. This industry is characterized by great diversity and a multiplicity of technologies applied on the factory work floor. There are no disruptive technologies that can revolutionize the industry in a relatively short time. The TMP that emerged from this study consisted of technology assumptions, modular acquisition, adaptation, and launching a technology. These are interwoven with an economic assessment, and each of these steps is formed by a set of activities that absorb time and employees’ efforts.

The study shows that the real TM is much more complex than it might have seemed from widely discussed literature models; some of the typical activities might not even appear, like knowledge protection activities in the studied cases. At the same time, intensive knowledge acquisition is observed as the key factor influencing the TMP. Precious architectural knowledge exists in an organization as so-called tacit knowledge, which is not practicable for protection in formal manners, as is postulated in many TM literature sources. It explains the lack of symptoms of knowledge protection activities undertaken by the studied companies. This study supports

suggestions expressed by some scholars that literature concepts offer an analytic framework of TM and that they reflect indifferently what happens in companies concerning organizational and workload sequences referring to handling technologies.

The sequence of introducing a new technology in a company is characterized by modularity. The final shape of technology emerges gradually, and many feedback loops and repeated assessments accompany this emergence. With many assessment points and many possible options, this gradual introduction allows a company to achieve well-tailored technology. A unique configuration of technology components is precious for companies because it leads to architectural innovations, which form an important competitive advantage. Technology modularity and frequent feedback loops are particularly important in this field.

Knowledge assimilation pacing influences the length and dynamics of TPMs in companies. Companies in spiral learning repeatedly exploit various knowledge sources. Studied TPMs are characteristic of by-the-way learning, which does not indicate that the knowledge is unimportant; it means the learning process is spread out in time and taking advantage of a variety of sources, means and kinds of knowledge; from inside and outside a company, where a company actively look forward to the most convenient options of effective learning. Observed incremental learning in the by-the-way mode implies that the knowledge (architectural knowledge) is the most desired asset in the TM, not just the technology itself, meant as a machine or a processing method, which is easy to obtain.

This study has a series of limitations, mostly rooted in the employed methodology. Qualitative insight into a few cases within one industry does not imply that this is a typical TMP for this industry. However, considering the small number of empirical studies on this issue, this study does contribute to the TM field. The observations presented above certainly cannot be extended to the whole metal processing industry; however, they might be a valuable starting point for further studies, both in-depth and quantitative, in this industry and in other industries where strictly protected and disruptive technologies do not exist. Companies' strategic and competitive importance of new technologies encourages empirical investigations focused on TM and TMP to be continued beyond emerging and rapidly developing industries.

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